UNIVERSITI PUTRA MALAYSIA

COMPUTER SIMULATION OF SURFACE PLASMON RESONANCE FOR OPTICAL MULTI-LAYER SYSTEM

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2000

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By

MOHAMED AHMED MOHAMED SIDDIG

Thesis Submitted in Fulfilment of the Requirements for the
Degree of Master of Science in the Faculty of
Science and Environmental Studies
Universiti Putra Malaysia

January 2000

Dedicated to

my

Parents;

Brothers

and Sisters.

Abstract of the thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirements of the degree of Master of Science

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Chairman: **Dr. Zainul Abidin Hassan**

Faculty: **Science and Environmental Studies**

Surface plasmon is a charge density wave on the surface of metals. The surface plasmon resonance technique is relatively new, and it is one of the most sensitive techniques to probe surface and interface effects. The Fresnel's equations and Snell's law are used to compute the reflection and transmittance of light incident on multilayers (series of N layers and N+1 interfaces) between semi-infinite ambient and substrate media. The effects of multiple reflection are taken care of by using 2×2 scattering matrix techniques. A plot of a graph for reflectance and transmittance can be obtained by varying the incident angle of a light beam at fixed frequency, or by varying the wavelength. Various plots of reflectance and transmittance as a function of incident angle, wavelength and interface parameters are displayed. The Visual

Basic 5.0 standard edition was used in this project whereby a window-based program with graphic user interface (GUI) was developed for the simulation of reflectance and transmittance. After the software program was developed, it was tested with four simulations with well-known experimental results to ascertain the reliability of the simulations. Some of the optical experiments for the both sections of program namely; the reflection and transmission versus incident angle and versus wavelength were simulated. These simulations were studied with Krestchmann's and Otto's configurations. The effect of variation of thickness, dielectric constants, incident angles and wavelengths were demonstrated. Based on the above simulation results, it can be concluded that the program is general enough and it can be used to simulate reflectance and transmittance for any materials.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

SIMULASI KOMPUTER UNTUK RESONAN PLASMON PERMUKAAN BAGI SISTEM BERBILANGLAPISAN

Oleh

MOHAMED AHMED MOHAMED SIDDIG

Januari 2000

Pengerusi: **Dr. Zainul Abidin Hassan**

Fakulti: **Fakulti Sains dan Pengajian Alam Sekitar**

Plasmon permukaan ialah gelombang ketumpatan cas yang wujud di permukaan logam. Teknik resonans plasmon permukaan ialah satu teknik yang agak baru diperkenalkan dan ia adalah antara teknik yang sangat sensitif untuk melihat kesan permukaan dan antaramukaan. Persamaan Fresnel dan Snell digunakan untuk mengira keterpantulan dan kehantaran cahaya yang ditujukan ke sistem berbilang lapisan (siri N lapisan dengan N+1 antaramukaan) yang berada di antara media ambien yang separuh infinit dengan media substrat. Kesan berbilang keterpantulan diambil kira dengan menggunakan teknik serakan matriks 2x2. Plot bagi graf keterpantulan dan kehantaran boleh diperolehi dengan mengubah sudut tuju untuk sinar tuju pada frekuensi cahaya yang tetap ataupun dengan mengubah panjang gelombang cahaya. Pelbagai plot keterpantulan dan kehantaran boleh diperolehi sebagai fungsi sudut tuju, panjang gelombang dan parameter permukaan. Bahasa pengaturcaraan Visual Basic 5.0 edisi standard telah digunakan untuk projek ini yang mana satu aturcara berasaskan kepada sistem tetingkap dengan antaramuka grafik digunakan untuk simulasi keterpantulan dan kehantaran bagi sistem berbilang lapisan. Setelah aturcara komputer selesai, ia diuji dengan empat simulasi yang mana hasilnya diketahui dengan baik untuk menentukan yang hasil simulasi boleh dipercayai. Ekperimen optik untuk kedua-dua bahagian aturcara komputer tersebut, yakni pemantulan dan penghantaran melawan sudut perlanggaran dan jarak gelombang, disimulasikan. Simulasi ini dibuat melalui konfugurasi Krestchmann dan Otto. Kesan dari perubahan ketebalan, pemalar dielektrik, sudut perlanggaran dan jarak gelombang ditunjukkan. Berdasarkan keputusan simulasi di atas, maka bolehlah disimpulkan bahawa atucara komputer yang dihasilkan berbentuk cukup umum untuk digunakan bagi simulasi keterpantulan dan kehantaran bagi sebarang bahan..

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Finally, may Allah reward the people who helped me directly or indirectly in finishing this work. I wish them every success in this life and hereafter under the guidance of Allah s.w.t.

I certify that an Examination Committee met on January 31, 2000, to conduct the final examination of Mohamed Ahmed Mohamed Siddig, on his Master of Science thesis entitled "Computer Simulation of Surface Plasmon Resonance for Optical Multi-layer System" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulation 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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This thesis was submitted to the Senate of Universiti Putra Malaysia and was accepted as fulfillment of the requirements for the degree of Master of Science.

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Date: 11 MAY 2000

DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

MOHAMED AHMED MOHAMED SIDDIG

Date: 14 / 2/ 2000

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LIST OF SYMBOLS AND ABBREVIATIONS

ATR	Attenuated Total Reflection.
β	Phase shift.
CEMS	Conversion Electron Mossbaur Spectroscopy.
EM	Electromagnetic wave.
ε_{1r}	The real part of dielectric constant for the 1^{st} Medium.
ε_{1i}	The imaginary part of dielectric constant for the 1^{st} Medium.
ε_{2r}	The real part of dielectric constant for the first layer.
ε_{2i}	The imaginary part of dielectric constant for the first layer.
ε_{3r}	The real part of dielectric constant for the second layer.
ε_{3i}	The imaginary part of dielectric constant for the second layer.
ε_{4r}	The real part of dielectric constant for the final medium.
ε_{4i}	The imaginary part of dielectric constant for the final medium.
d1	The thickness of the first layer.
d2	The thickness of the second layer.
GUI	Graphic User Interface.
IMD	Ideal Modelling Distribution.
K_c	Wave Vector of Light.
K_{sp}	Wave Vector for the plasmon.
K_x	Component of wave vector in x-diection.
K_z	Component of wave vector in z-diection.

LSF	Least Square Fitting.
μ	Magnetic permittivity.
PSA	Phase Space Analysis.
σ	Specific conductivity.
r_p	reflection coefficient for wave incidence parallel to the plane of incident.
r_s	reflection coefficient for wave incidence perpendicular to the plane of incident.
$R(\lambda)$	Reflectance versus wavelength.
$R(\theta)$	Reflectance versus incidence angle.
S	scattering matrix.
SP	Surface Plasmon.
SPP	Surface Plasmon Polaritons.
SPR	Surface Plasmon Resonance.
STM	Scanning Tunneling Microscopy.
TIR	Total Internal Reflection.
t_p	Transmission coefficient for wave incident parallel to the plane of incident.
t_s	Transmission coefficient for wave incident perpendicular to the plane of incident.
$T(\lambda)$	Transmission versus wavelength.
$T(\theta)$	Transmission versus incident angle.
ω	Frequency.
ω_p	Natural plasma frequency.
XRR	X-Ray Reflectance.

CHAPTER I

INTRODUCTION

Objective

The objective of this project is to develop a computer program for properties of multilayered system. This is done by computing reflection and transmission for such a system. The effect of multiple scattering for such system had led by using scattering matrix techniques. The computation is done with Visual Basic as programming language. The choice of language is a matter of convenience for it is graphic user interface (GUI) and event-driven programming in windows system.

Surface Plasmon Resonance (SPR)

The surface plasmons are charge density waves which propagate along the surface of plasma. Any system which can be approximated as plasma will exhibit the phenomena. For example, electrons in metal can be approximated as free electrons systems.

Hence metal sheet can be treated as a plasmon slab. Then it is possible to excite plasmons on the surfaces of metals. The surface plasmon resonance technique is a technique of generating surface plasma waves using appropriately applied perturbation such as light waves. Since the technique probes the surface of metals, hence any surface effect can be detected.

SPR has been applied in the development of gas sensor, measurement of optical properties of metals and degeneration monitoring of metals (Agranovich and Mills, 1982). SPR has an extensive range of applications in the analysis of metals because the resonance condition depends upon the physical properties of metal surface on which the plasmon is excited. SPR is one of the most sensitive technique to probe surface and interface effects. This inherent property makes SPR well suited for nondestructive studies of surfaces, interfaces, and very thin layers (Kryakov, 1997). Surface plasmons can be excited by either electron beams or light rays. However surface plasmons cannot be normally excited optically in metal- dielectric interface because the dispersion relation for SPR and incident light do not match at any frequency. This restriction however can be overcome by using the prism (see figure 1).

SPR Principle

Surface plasmon resonance is an opto-electrical phenomenon arising from the interaction of light with free electrons in metal surface. Under certain conditions

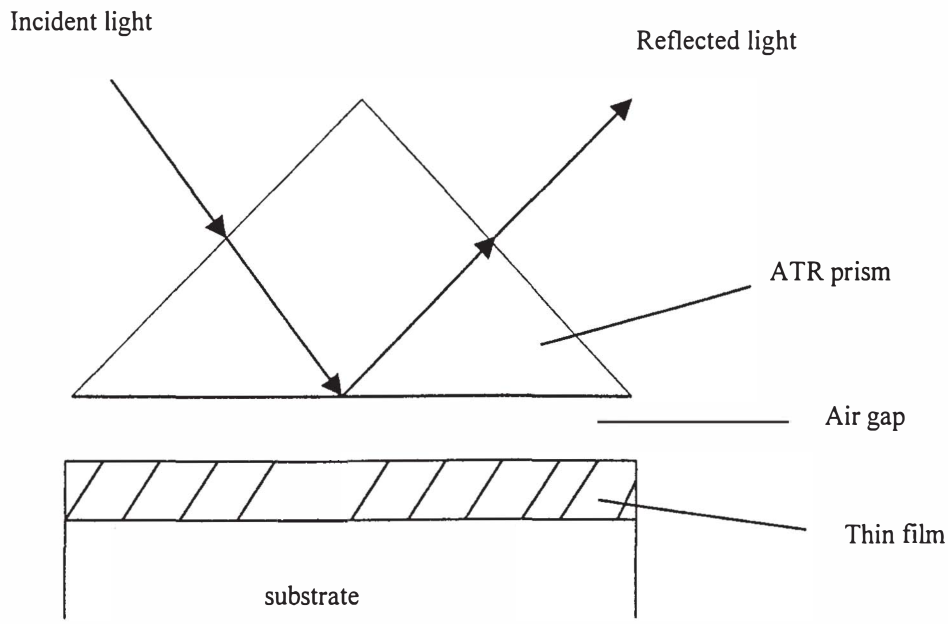

Figure 1 Prism Used to Overcome the Restriction of Excitation of Surface Plasmon in Metal-dielectric Interface.

the energy carried by photons of light is transferred to packets of electron density wave called plasmons on the metal's surface. Energy transfer occurs only at specific resonance wavelength of light i.e. the wavelength in which the quantum energy carried by the photons exactly equals the quantum energy level of the plasmons. The resonance wavelength can be determined very precisely by measuring the light reflected by a metal surface. At most wavelengths the metal acts as a mirror reflecting virtually all the incident light. At the wavelength that fulfils the resonance conditions, the incident light is almost completely absorbed. The wavelength at which maximum light absorption occurs is the resonance wavelength. The SPR resonance wavelength is determined by three factors namely the type of metal, the structure of the metal's surface, and the nature of the medium in contact with the metal surface [Feuerbacher et al., (1978) Garcia and Perdry, (1994)].

The Metal

To use SPR, a material must have conduction band electrons capable of resonating with light at suitable wavelength. The visible and near-infrared parts of the spectrum are particularly convenient because optical components and light performance detectors appropriate for this region are readily available. A variety of metallic elements satisfy this condition. They include silver, gold, copper, aluminum, sodium, and indium. The surface exposed to light must be pure metal (Garcia and Perdry, 1994).

The Surface

The resonance condition that permits energy transfer from photons to plasmons depends upon a quantum mechanical criterion related to the energy and momentum of the photons and plasmons. Both the energy and momentum of the photon must match exactly the energy and momentum of the plasmons. For a flat metal surface, there is no wavelength of light that satisfies this constraint. Hence, there can be no surface plasmon resonance (Feuerbacher et al., 1978). The metal surfaces are considerably smoother electronically than semiconductor surfaces because of the delocalised electron on metallic boundary. Even though the localized